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Stone Disease

The "All-Seeing Needle": Initial Results of an Optical Puncture System Confirming Access in Percutaneous Nephrolithotomy

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Abstract

Background: In percutaneous nephrolithotomy (PNL), the best possible way to access the collecting system is still a matter of debate. There is little possibility of correcting a suboptimal access.
Objective: To describe our initial experience using a micro-optical system through a specific puncture needle to confirm the quality of the chosen access prior to dilatation of the operating tract.
Design, setting and participants: Micro-optics of 0.9- and 0.6-mm diameter were used. The micro-optic with integrated light lead was inserted through the working sheath of the puncture needle. The modified needle had a 1.6-mm (4.85-Fr) outer diameter. The optical fiber was connected via a zoom ocular and light adapter to a standard endoscopic camera system. For sufficient intraoperative sight, an irrigation system was connected.
Intervention: The optical puncture needle was used in 15 patients for renal access prior to standard PNL procedures.
Measurements: The optical assessment included determination of the distortion, resolution, angle, and field of view. The irrigation flow was assessed in an ex vivo setting, with the puncture stylet or the needle shaft either empty or with a 0.018-in guidewire inserted.
Results and limitations: In all cases, visualization of the punctured kidney calyces was successful and the presence of the target calculi could be confirmed prior to guidewire placement and tract dilation. The 0.9-mm optic was found to be significantly superior in all optical parameters in contrast to the 0.6-mm optic. No significant complications were observed.
Conclusions: The optical puncture needle for PNL appears to be most helpful for confirming the optimal percutaneous access to the kidney prior to dilation of the nephrostomy tract, improving the safety of the technique.
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1. Introduction

In 1976, Fernstrom and Johannson established a percutaneous tract with the intention of removing a renal pelvic stone [1]. It soon became apparent that it was possible to perform percutaneous procedures through an acutely dilated tract. In the 3 decades that have passed since percutaneous nephrolithotomy (PNL) was first described, PNL has undergone significant changes and is continuing to evolve, with attempts being made to popularize the technique by improvements in instruments (ie, introduction of flexible scope technique, downsizing of nephroscopes and tubes) and patient positioning (ie, prone and supine) [2–5]. Although remaining the most complex renal-stone surgery technique, PNL has become the consensus first-line therapy for calculi >2 cm in diameter and is the treatment modality of choice for complex renal stones. Stone-free rates ranging from 78% to 95% make PNL a highly efficient procedure [5,6]. Complications may develop immediately from the initial puncture; therefore, establishing an optimal and atraumatic access to the pelvic system is the most important initial step in a successful PNL procedure [6,7]. Correct access to the renal collecting system is mainly achieved under fluoroscopic control, or using an ultrasound (US)-guided puncture or a mixed procedure.

We describe our initial experience of using a micro-optical system through a particular puncture needle to visually confirm the quality of the chosen access prior to dilating the operating tract.

2. Materials and methods

The system consists of sterilizable microfiber optics of 0.9- and 0.6-mm diameter, with resolutions of 6000 and 10 000 pixels (PolyDiagnost, Pfaffenhofen, Germany). The micro-optic with integrated light lead is inserted either in the puncture stylet or the working sheath of the puncture needle. The modified three-part needle (PolyDiagnost, Pfaffenhofen, Germany) has a 1.6-mm outer diameter (4.85 Fr/16 gauge) that is slightly larger than the diameter of a standard 1.3-mm/18 gauge needle. The inner stylet that incorporates the optical fiber during puncture has a 1.3-mm (3.9 Fr) outer diameter. The needle comprises a Y piece with an outlet for the irrigation system. An irrigation pump (IP 200, PolyDiagnost, Pfaffenhofen, Germany) or 20-ml syringes operated manually can be used for irrigation. The optic length is adjusted inside the needle sheath via a slide adapter (Fig. 1). The optical fiber is connected via a zoom ocular and light adapter to a standard endoscopic camera system and to a xenon light source. The ocular, camera, and light cables are separated outside the sterile field and are mounted on a four-joint arm, which allows easy positioning of the nonsterile components relative to the operating side. The specifications of the puncture needle are given in Table 1.

Table 1 – General specifications of the puncture-needle system

Needle shaft	
Outer diameter, Fr/mm	4.85/1.6
Inner diameter, mm	1.4
Working length, mm	200
Puncture stylet	
Outer diameter, Fr/mm	3.9/1.3
Inner diameter, mm	1.05
Working length, mm	203

2.1. Optical assessment

Each test was performed in an experimental setup with a CS 207 camera, 15-in monitor, and a LS 200 xenon light source (PolyDiagnost, Pfaffenhofen, Germany).

2.1.1. Optical resolution

Resolution was measured using an industry-standard, US Air Force (USAF), resolving-power, 1951 test pattern compliant with US government specification MIL-STD-150 A (Newport Corp, Irvine, CA, USA). The USAF resolution target consists of a repeating series of parallel bars sequentially decreasing in size and separated into group and element numbers. The test target expresses resolutions in terms of line pairs (LP) per millimeter. The needle tip, immersed in 0.9% saline, was fixed at the minimal distance from the target where a clear picture could be identified on the display. The target was set up vertically and centered. By moving the distal tip in the vertical plane facing the optical-resolution target, the on-axis resolution of the endoscope was determined in LP per millimeter. The off-axis resolution was similarly determined. Being a subjective qualitative measurement, the procedure was performed by three investigators.

2.1.2. Optical distortion

Optical distortion is an aberration of the lens (optical error) that causes a difference in the magnification of the object at different fractions in the field of view. It was calculated using the following formula: percent distortion = (actual distance − predicted distance) / predicted distance × 100. To measure the distortion of the optical systems, the needle tip was fixed 10 mm from a distortion test chart (Edmund Optics Inc., Barrington, NJ, USA).

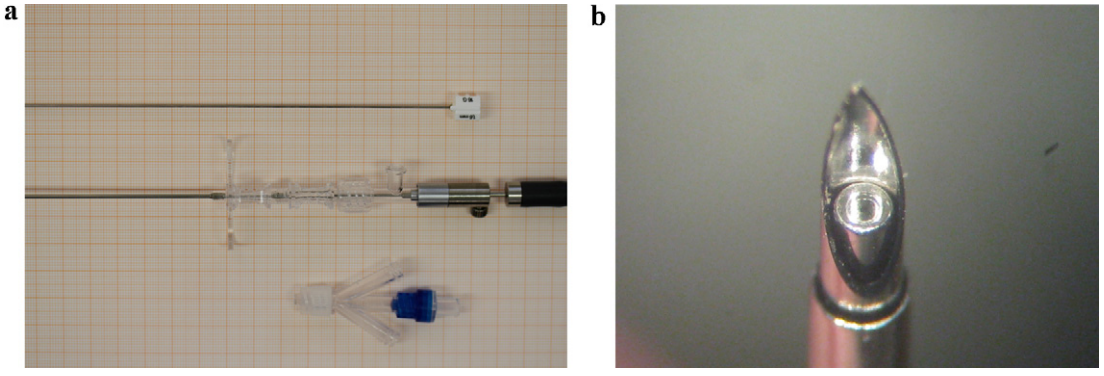

Fig. 1 – The optical puncture system. (a) The optical system coupled into the needle shaft and additional adapter; (b) tip of the needle with the optical system inserted.

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Table 2 – General specifications of the microfiber optics

Fiber optic	6000 pixels	10 000 pixels
Outer cover	Nitinol	Nitinol
Outer diameter, mm	0.55	0.90
Length, mm	275	275
Illumination bundles, fibers (No.)	1 (60)	1 (200)
Resolving power, LP/mm		
On-axis	16.0	17.96
Off-axis	14.25	16.0
Distortion, %	−12.1	−53.0
Field of view in air	70	120
Field of view in water	53	105
Angle of view, degree	5.9	1.4
Light output, $Lux_{100\%\ intensity}$	2.700	16.800

LP = line pairs.

2.1.3. Field and angle of view

The field and the angle of view were determined by aiming the needle system perpendicular to a target plane. The field of view was determined by the angle that spans the total field of view (ie, the largest visible circle of the target plane). The angle of view was defined as the difference between the central viewing direction and the mechanical axis of the needle tip.

2.2. Irrigation flow assessment

Irrigation flow was assessed for the 10 000-pixel optic inserted in an ex vivo setting, with either the puncture stylet or the needle shaft empty or with a 0.018-in, floppy, J-tipped guidewire inserted. The Y piece was connected to the irrigation pumping system set to pressures of 50 and 100 mm Hg. Flow measurements were performed using normal saline (0.9% NaCl) at room temperature. The needle system was placed horizontally and the fluid outflow collected over a specific time interval into a graduated cylinder and the mean flow rate recorded.

2.3. Clinical application

The optical puncture needle was used in 15 patients for renal access prior to standard PNL procedures (Table 3). All procedures were performed under general anesthesia in the prone position as a one-stage operation. Access to the pelvicaliceal system was obtained under US guidance using a 3.5-MHz probe. Prior to puncture, the needle with incorporated optical system was inserted in the puncture-guide attachment. The skin was punctured at the posterior axillary line and the pelvicaliceal system was entered at the lower posterior calyx.

Once the target calyx was identified, entry through the subcutaneous tissue, muscle layer, and surrounding fatty tissue into the collecting system was visualized in real time via the video monitor, making fluoroscopy monitoring dispensable. Once percutaneous access was obtained, the needle stylet was removed and a 0.018-in, floppy, J-tipped guidewire was inserted into the needle shaft parallel to the optical fiber and placed under direct endoscopic control to a position facilitating the passage of the dilating devices. The needle was removed and the position of the working wire was monitored using fluoroscopy. The tract was dilated using coaxial telescopic dilators to 30 Fr and an Amplatz sheath (Cook Medical Inc., Bloomington, IN, USA). Nephroscopy was performed using either a rigid or flexible nephroscope.

3. Results

3.1. Optical assessment

The results of the optical measurements are presented in Table 2. The average angular resolution, the distortion, and the fields of view in air and in water showed superior results for the 10 000-pixel optic. The crucial factor for exclusively using this fiber in the clinical setup was the predominant indicated value for light output: An approximately six times greater light output was achieved.

Table 3 – Irrigation flow rates (milliliters per minute) at different pressure points (10 000-pixel optic inserted)

	50 mm Hg	100 mm Hg
In the stylet	16	23
In the needle shaft (empty)	100	120
In the needle shaft inserted with 0.018-in guidewire	80	110

3.2. Irrigation flow assessment

Table 3 shows the irrigation flow rates with the 10 000-pixel optic inserted. With the puncture stylet inserted, the irrigation flow was 16 ml/min with 50 mm Hg and 23 ml/min with 100 mm Hg pressure. The flow rate was greatest with an empty needle shaft at 120 ml/min with 100 mm Hg pressure. Insertion of a 0.018-in guidewire reduced the flow rate by 8% at 50 and 100 mm Hg pressure, respectively.

3.3. Clinical application

Direct comparison of the optical properties showed the 105° field of view (in water) of the 10 000-pixel optic to be superior for confirmed visualization compared to the 53° field of view (in water) of the 6000-pixel system. The wider field of view overcame the obstacle of restricted axial needle movement due to the outer diameter and section thickness of the needle shaft. With the 10 000-pixel optic inserted, the residual lumen for irrigation was reduced to 14.3% compared to 42.6% using the 6000-pixel optic. The temporary use of an irrigation pumping system, however, assured the purification of the optic fiber from puncture-related tissue adherences and enabled higher visibility.

In all 15 cases, visualization of the punctured kidney calyces was achieved and the presence of the target calculi could be confirmed prior to tract dilation. In four patients, the optical confirmation of the pelvicaliceal system yielded a suboptimal placement of the needle with the utmost probability of creating a poor tract; therefore, optical repuncture was mandatory. In three patients, due to an unfavorable needle angle, it was not possible to direct the guidewire in either another calyx or down the ureter to provide further secure access. In one patient, the initial puncture was conducted at an inappropriate angle to the target entry calyx, leading to a missed puncture and consecutive failure to hit the target. Clinical data are shown in Table 4. The ability to smoothly insert and operate a 220-μm holmium laser fiber may represent a therapeutic option for specific clinical scenarios (Fig. 2b).

4. Discussion

Optimal percutaneous access is established by traversing the shortest straight distance from the skin through a

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Table 4 – Clinical data

Patients, no.	15
Mean age, yr (range)	49.4 (23–80)
Sex ratio (F:M)	6:9
BMI, kg/m^2, mean (range)	27.5 (24.8–30.2)
Stone location, No.	
Lower calyx	7
Upper calyx	1
Pelvis	7
Stone size, mm, mean (range)	30.4 (12–85)
Patient position	Prone
Single tract access, No. (%)	15 (100)
Visual confirmation, No. (%)	15 (100)
Repuncture, No. patients	4
Operative time, min, mean (range)	101.4 (74.6–128.2)
Significant complications	None
Postoperative clearance at 6 wk, No.	
Complete	11
Residual fragments	4
Additional procedures, No. patients	
Ureterorenoscopy	3

BMI = body mass index.

papilla and the target calyx into the renal pelvis [8–10]. The method of choice for access depends mainly on training status and personal preference: Access to the renal cavities can be achieved either by fluoroscopy guidance after a retrograde (contrast and/or air) pyelogram or by US-guided puncture, or the combination of both techniques [2,8–10]. As surgeons and patients are exposed to high levels of x-ray radiation during percutaneous surgery, minimizing the shortcomings and side effects of extensive radiation exposure during PNL procedures is of great relevance. Therefore, US-guided puncture techniques with the patient in either the prone or supine position have become reasonable alternatives to fluoroscopy-controlled puncture [3,8,11–13]. Initial US-guided puncture is useful to define the most appropriate angle toward the target entry calyx. US additionally allows the evaluation of the possible interposition of the splanchnic organs between the skin and the kidney.

PNL-related complication risk is influenced by many factors, including operative technique, patient status, and renal-stone complexity. Blood loss is a common occurrence during PNL, presenting intraoperatively and postoperatively with varying severity. Intraoperative bleeding frequently occurs from needle passage, secondary to parenchymal lacerations incurred during tract dilation, over advancement of the sheath into the parenchyma, or from stone disintegration [14–17]. In renal arterial bleeding, a high-pressure system will leak into a low-pressure system of a vein, leading to arteriovenous fistula (AVF) formation.

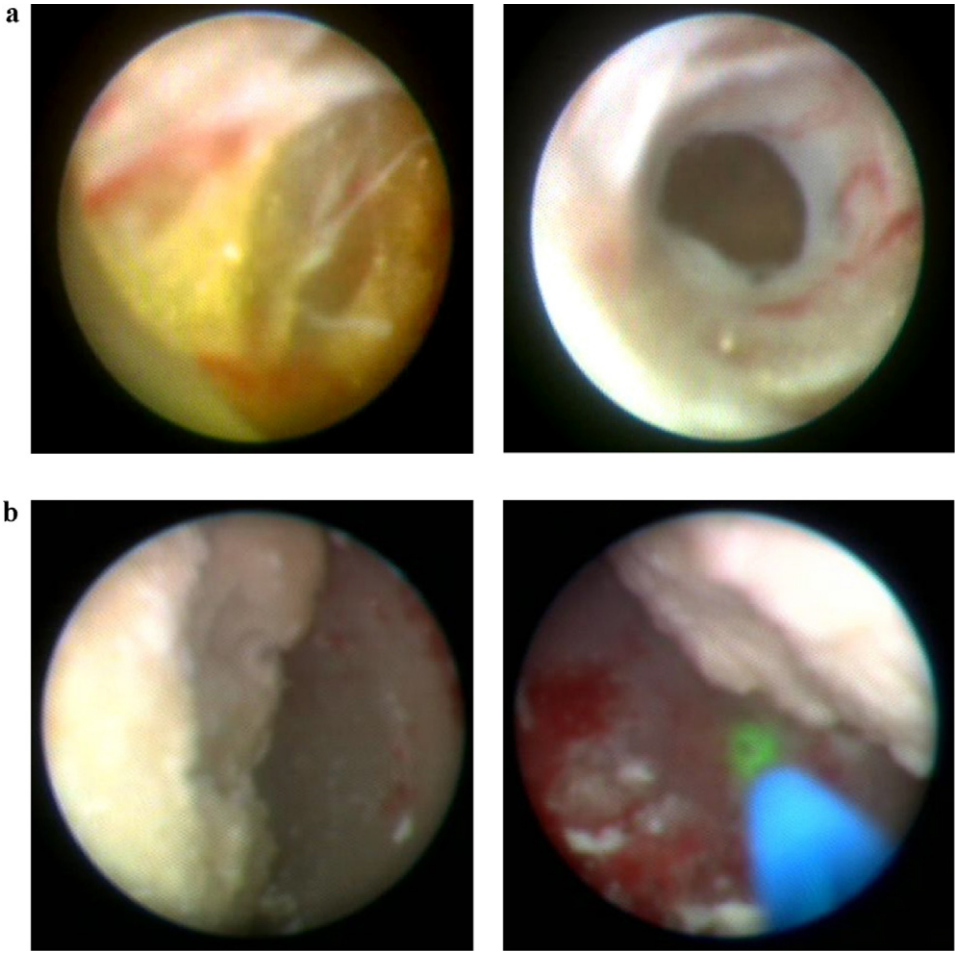

Fig. 2 – (a) Intraoperative view (fatty surrounding tissue of the kidney and prior to the collecting system); (b) intraoperative view (without and with insertion of a 220-μm holmium laser fiber).

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Leakage into the renal parenchyma leads to pseudoaneurysm formation [14–17]. In the majority of cases, delayed bleeding results from pseudoaneurysm rupture [16,17].

The initial puncture, therefore, should be transparenchymal posterolateral along the direction of the infundibulum. Entering the fornix of a posterior calyx traverses minimal calical tissue, thereby avoiding injury to any interlobar arteries and larger intrarenal vessels[14–17]. Tract dilatation must not proceed too far medially due to the risk of perforation of the renal pelvis with concomitant laceration of the hilar vessels [15,18]. Minimal angulations of the dilation system, the working sheath, and nephroscope shaft, avoiding extensive torquing and the use of flexible nephroscopes for calculi in inaccessible calices, are techniques to additionally diminish parenchymal bleeding [15]. The frequency of major hemorrhage requiring blood transfusion after percutaneous surgery has been reported to range from 5% to 18%, with 0.3% to 1.4% of cases requiring angiographic intervention [6,8,15,19,20]. Several studies tried to identify significant predictors of blood loss and the resulting need for transfusion. In their multivariate regression analysis of 301 PNL procedures, Kukreja et al showed that operation technique-related factors, like method of access (fluoroscopy vs ultrasonography), method of tract dilatation, two or more tracts, size of the tract, and occurrence of operative complications were among the significantly predictive factors of blood loss [8]. In their retrospective study of 193 PNLs, Turna et al identified access-related factors, such as the number of tracts and method of dilatation, among the variables related to a high incidence of hemorrhage [21]. El-Nahas et al predicted, in a large series of 3878 PNL procedures, risk factors for extensive postinterventional hemorrhage, which occurred in 1% of patients. Among the significant variables for severe bleeding were multiple punctures, upper caliceal puncture, the existence of a solitary kidney, staghorn stone, and the inexperience of the surgeon [22]. Distressing complications of PNL are injuries to adjacent organs; these occur rarely, but bear serious consequences for the patient. The risk of an injury of the pleura and the lung is about 2.3–3.1% [6,15]. The risk of colonic injuries is about 0.2–0.8%. Colonic perforation may occur, when the puncture site is placed extremely lateral to the posterior axillary line [6,15,23].

The most crucial step within the steep learning curve in the training of PNL is the ability to obtain an appropriate renal access. Inaccurate placement of the needle can cause injuries in the kidney and adjacent organs, thus compromising the planned percutaneous procedure as well as the clinical outcome of the patient. Previous reports on the learning curve of PNL suggest 60 PNL procedures for surgical competence and 115 procedures for excellence [24–26]. The combination of US and optical guidance allows the surgeon to safely identify the location of the needle inside the internal structure of the kidney immediately upon entry. Visually guided direct control of the puncture and insertion of a working wire in a stable position therefore excludes puncture-related complications. With the optical puncture system, direct visual confirmation of the three-dimensional calyceal anatomy facilitates the conversion into the two-dimensional images obtained from fluoroscopy or US, and therefore helps gain and maintain surgical competence. The optical puncture is suited to achieving optimal access to the renal cavities and avoiding perforation of the collecting system and other complications related to poor access.

It appears that optical puncture guidance helps improve skills in performing percutaneous access and therefore overcomes a crucial step in the learning curve of PNL. This, as well as the role of the optical puncture needle in multiple-tract percutaneous-access procedures, or in procedures performed in the supine position, as well as its therapeutic extensions will be investigated in future trials.

5. Conclusions

The key requisite to any successful percutaneous procedure is good access by traversing the shortest straight distance from the skin to the collecting system. Obtaining optimal renal access is a crucial step in the learning curve of PNL and remains a challenging task for many urologists. The optical puncture system directs and facilitates initial access and therefore overcomes one of the most important difficulties in performing percutaneous nephrolithotomy.

Author contributions: Christian Gratzke had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study concept and design: Bader, Desai, Stief.
Acquisition of data: Bader, Seitz, Gratzke.
Analysis and interpretation of data: Sharma, Seitz, Bader.
Drafting of the manuscript: Bader, Gratzke, Desai.
Critical revision of the manuscript for important intellectual content: Stief, Desai, Gratzke.
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